Optimal Economizer Control of VAV System using Machine Learning

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Abstract. Energy efficiency of the HVAC system can be improved through system renovation and operating method improvement. Economizer control, one of the energy efficient measures through improvement of operating method, introduces outdoor air when outdoor air is sufficient for cooling. There are high/low limit that determine the range of economizer control and mixed air temperature as control set-points. Economizer is controlled with the user's or manager's experience, and the set-point is operated fixed. This causes problems energy waste because it does not consider indoor and outdoor environments. Therefore, the purpose of this study is to develop an optimal economizer control of VAV system that resetting the set-point considering the indoor and outdoor environments. To this, a machine learning model was used to develop a model that predicts the future state based on the current state. Based on the developed prediction model, the optimal economizer control of VAV system that resets the mixed air temperature set-point in real time was developed and the control method was evaluated through simulation. As a result, it was confirmed that the mixed air temperature set-point changed in real time, and that about 20% of energy consumption was saved compared to the existing dry- bulb temperature control.

1 Introduction

The energy consumption of the heating, ventilating, and air conditioning (HVAC) system accounts for the majority of energy consumption in the building sector[1]. In order to reduce the energy consumption of HVAC system, the performance and energy management are essential, and the energy efficiency of HVAC system can be improved through system renovation and operating method improvement. The economizer control is one of the energy-efficient measures to improve operating method. This control is to reduce the cooling load by introducing outdoor air in the middle season. That is, the economizer control is to use the outdoor air for cooling by controlling the outdoor air, return, and exhaust dampers to maintain the mixed air temperature set value when the outdoor air temperature or enthalpy is lower than the indoor air temperature or enthalpy [2]. The economizer control method includes dry-bulb temperature control that determines the amount of outside air introduced based on dry-bulb temperature, and enthalpy control that determines the amount of outside air introduced based on enthalpy [3]. The set-points of the economizer control have high/low limit that determine the economizer control range and the mixed air temperature.

The mixed air temperature set value is generally set to 13℃ and ASHRAE standard 90.1 suggests the high limit for economizer according to the climatic conditions, and the Engineering Equipment Manual proposes the high limit to 18℃[4][5].

Bakke evaluated the performance of the economizer. This study was investigated various climatic zones and evaluated the effect of the lower limit set value on energy consumption during economizer control [6]. Lee et al analyzed the energy saving effect according to the change in the supply air temperature when controlling the economizer dry-bulb temperature and enthalpy control, and confirmed that additional energy savings are possible compared to the existing control when supply air temperature changes according to the outside temperature [7]. Seong et al compared the performance according to the economizer control method and the change in the control setting of outdoor air intake in order to suggest the optimal economizer control method and settings for efficient outdoor air intake [8]. Gang et al developed a steady-state energy consumption model to find the optimal supply temperature to minimize the energy cost during the economizer control of the HVAC system. In addition, the optimal supply temperature according to the outdoor and indoor conditions was suggested, and it was applied and evaluated [9]. Lee et al confirmed that the set value of the mixed air temperature that consumes the minimum energy according to the load is not constant when controlling the economizer dry-bulb temperature in constant air volume (CAV) single duct system. Based on this, a control method for resetting the mixed air temperature

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set value according to the load was proposed [10]. Likewise, many studies on economizer control set-points are being conducted, but there is a lack of studies on set-points considering real-time weather and HVAC system load conditions. Therefore, the purpose of this study is to develop an optimal economizer control of variable air volume (VAV) system that resetting the set-point considering the indoor and outdoor environment.

For economizer optimal control, it is necessary to predict and control the future state of the system based on the current state, but it is difficult to predict the future of the system. With the automation of buildings, technologies such as big data and artificial intelligence are being used as tools for predicting building energy consumption, predicting performance of HVAC system, and system optimization and real-time control by converging with building mechanical systems [11]. Among data-driven models, machine learning models are attracting attention as a tool for developing predictive models in buildings.

The purpose of this study is to develop an optimal economizer control that produces the maximum outdoor air-cooling effect. To this end, this study developed a data-driven prediction model and developed an optimal economizer control of VAV system to predict the optimal mixed air temperature set-point using the developed prediction model, and evaluated the control method through simulation. This study used MATLAB to develop the prediction model, and TRNSYS 17, a dynamic simulation tool, was used to evaluate the optimal economizer control performance. In addition, a co-simulation between MATLAB and TRNSYS 17 was constructed and used to evaluated the economizer optimal control.

2 Development of prediction model

Economizer control, which is one of the energy efficient measures of buildings, adjusts outdoor air, return, and exhaust dampers to maintain a mixed air temperature set-points. If economizer is not controlled to an appropriate set-points considering the indoor and outdoor conditions of the buildings, energy waste may occur. Therefore, set value automation considering indoor and outdoor condition is required. Among the data-driven models, ANNs can predict nonlinear patterns with excellent performance, so it is used in building sector such as building load and energy prediction. For optimal control of economizer, it is necessary to predict and control the future state of the system based on the current state, but it is difficult to predict the future of the system. Therefore, it is necessary to develop a prediction model using the ANN model for optimal economizer control.

In this study, the sensible and latent heat load, indoor CO_2 concentration, and energy consumption prediction model are developed to predict the optimal mixed air temperature. The prediction model development proceeded in the order of learning data collection, input variable selection, initial model development, prediction model optimization, and prediction model development and validation.

The target building selected for this study is a university's laboratory located in Korea, with an area of 77.8m^2. Table 2 shows an overview of the target building and system, in which a single duct VAV system and terminal unit with reheat coil are installed in the target building.

Table 1. Overview of target building.

Element		Style
Building	Location	Korea
	Use	Laboratory
	Area	77.8 m^2
System	AHU	Single duct VAV system
	Terminal unit	Terminal unit with reheat coil

To develop an ANN model, it is necessary to acquire sufficient amount and high quality data. To implement a prediction model with high accuracy, high-quality training data must be collected. There was a limit to securing the actual measurement data of the selected target building, TRNSYS 17, which is a detailed building analysis program, was used to collect learning data [12]. For simulation through TRNSYS 17, the target building was 3D modeled through Google Sketch up (v8.0) program. The architectural elements of the building were modeled through TRNbuild, and the mechanical system was modeled with simulation studio. In this study, climate data provided by TRNSYS was used and data of 'Ulsan', one of cities in Korea, was used. Also, the indoor set temperature and relative humidity were set to 24℃, 50% according to the indoor temperature and relative humidity standards for calculating the capacity of heating and cooling mechanical system in the energy-saving design standards of buildings.

To collect the training data required for the prediction model, the data was collected by changing the mixed air temperature set value from 10℃ to 24℃ at intervals of 1℃, and the number of occupants from 0 person to 4 people at intervals of 1 person. And the input variables of the prediction model were selected through the analysis of the person correlation coefficient and the coefficient of determination of the collected data and the predicted data. For the development of prediction model, MATLAB (R2014a) was used and functions built into the program were used [13]. Among the training data sets constructed during prediction model, 70% of randomly selected data was used for training, 15% was used as validation data, and the remaining 15% was used as test data. The data of the constructed input variables have different ranges and units, and in order to improve the learning and prediction performance of the ANN by minimizing the weight bias when learning the prediction model using the training data set was replaced with a value between 0 and 1. The structure of the hidden layer of the initial ANN model developed was composed of 1 layer and 2n+1 hidden neuron [14]. In addition, an optimization model was derived by optimizing the number of hidden layer and the number of hidden neurons. A prediction model was developed based on the derived optimal hidden layer composition, and the performance of the developed prediction model was evaluated by the Mean Bias Error (MBE), CV(RMSE) (Coefficient of Variation of the Root Mean Square Error) and R^2.

3 Optimal economizer control of VAV system

3.1 Propose optimal economizer control algorithm

When controlling the economizer, the mixed air temperature set value is controlled at a constant value. In this way, if the set value is constantly controlled without considering the indoor and outdoor conditions, energy waste may occur. Therefore, it is necessary to automate the set value considering the indoor and outdoor conditions. In this study, an economizer optimal control that resets the mixed air temperature using machine learning was developed. To this end, a building load and CO_2 prediction model was developed. In addition, for real-time energy prediction, an energy consumption prediction model considering building load, CO_2, and mixed air temperature was developed (Chap. 2). In addition, based on the predicted models, the mixed air temperature set value for the situation where energy consumption is minimal was derived, and the detailed control method is as follows.

Step 1: Operational data is passed to Matlab and sensible load, latent loads and CO_2 concentration are predicted based on operational data

Step 2: Predicting energy consumption according to predicted values(sensible load, latent load and CO2 concentration) and mixed air temperature set value change

Step 3: Based on the energy consumption prediction result, the mixed air temperature set value that consumes the minimum energy is derived

Step 4: Apply the derived set value as the economizer control set value of the next time-step

3.2 Construct co-simulator

The optimal economizer control was evaluated using a simulation program. For this, co-simulation between TRNSYS 17 and MATLAB was constructed. Figure 2 shows the conceptual diagram of co-simulation. The target building was modeled through TRNSYS 17 (Chap. 2), and a prediction model was developed through MATLAB. Input values like outdoor air temperature, outdoor air humidity, outdoor air intake ratio and supply air flowrate to be used for prediction are transmitted from TRNSYS to MATLAB in real time and sensible and latent heat loads, CO_2 concentration and energy consumption are predicted using the prediction model. Based on the predicted result, it is possible to predict the optimal mixed air temperature set value in the situation where the energy consumption is minimum, and the value is transmitted from Matlab to TRNSYS and applied as the set value of mixed air temperature of the next time-step.

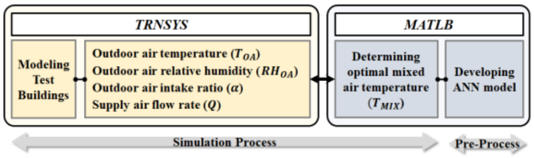

Fig. 2. Schematic of co-simulator

4 Result analysis and discussion

In this chapter, the effect of economizer optimal control of VAV system through real-time resetting of the mixed air temperature set-point was analyzed on the indoor thermal comfort and energy performance. At this time, it was compared with the existing dry-bulb temperature control. The set value for controlling the economizer dry-bulb temperature control was set as follows. The mixed air temperature set value was 13°C, and the high limit for economizer was 18°C.

Figure 3 shows the change in indoor thermal comfort and mixed air temperature (MAT) set value according to the application of the optimal economizer control. When the optimal economizer control was applied, the mixed air temperature continuously changed with time unlike the existing control using a constant value. And in terms of indoor thermal comfort, the indoor air temperature (IAT) all year round satisfies the set value within ±2°C, and the indoor relative humidity (IRH) was maintained below 60%.

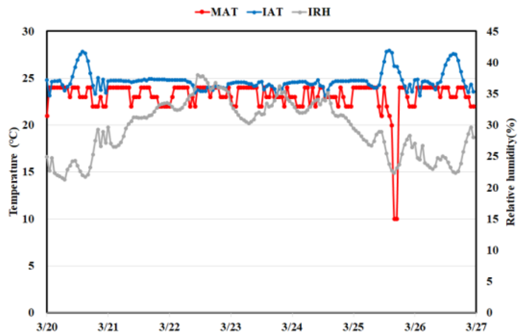

Fig. 3. Total energy consumption according to economizer control

The evaluation results of energy consumption according to the optimal economizer control of VAV system are as follows. In the case of cooling energy consumption, energy consumption was saved by applying the economizer optimal control compared to the existing dry-bulb temperature control during the cooling period. This is judged to be the result of the increase in the period controlled by the economizer optimal control compared to the existing control. In addition, in the case of fan energy consumption, the energy consumption increased in some months according to the application of the optimal economizer control, but the energy consumption decreased in most months. This is because the supply air volume was affected as the mixed air temperature set value changed. Regarding the reheating energy consumption during the heating season, compared to the existing control, the set value of the mixed air temperature was maintained high, resulting in a decreased in reheating energy consumption. Figure 4 shows the overall energy consumption. The mixed air temperature changes according to indoor and outdoor conditions had an effect on energy consumption. Therefore, compared to the existing economizer dry-bulb temperature control, energy consumption was saved by applying the economizer optimal control, and the reduction rate is about 20%.

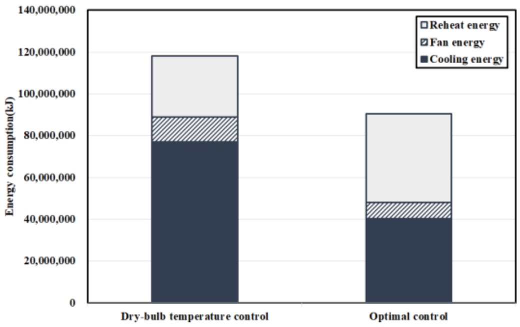

Fig. 4. Total energy consumption according to economizer control

5 Conclusion

In this study, the economizer optimal control of VAV system was developed by resetting the mixed air temperature set value in real time to maximize the outdoor cooling effect. To this, a prediction model was developed using machine learning, an optimal economizer control was developed through prediction of the optimal mixed air temperature set value, and the developed control method was evaluated using simulation. The results of this study are as follows.

This study developed a sensible load, latent load, indoor CO_2 concentration, and energy prediction model using machine learning was developed using MATLAB to predict the optimal mixed air temperature set value. And, using the developed prediction model, an optimal economizer control algorithm for the VAV system was developed by resetting the set value that satisfies the indoor thermal comfort and IAQ and consumes minimum energy consumption. In addition, the developed control was evaluated through simulation, and a co-simulator between MATLAB and TRNSYS was constructed for this. As a result of the evaluation of the developed control, the indoor temperature was within ±2℃ of the set value, and the indoor relative humidity was maintained below 60%. The mixed air temperature set value was changed in real time, and accordingly, the energy consumption was reduced by about 20% compared to the existing dry-bulb temperature control.

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